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# Environmental Solutions: Commercializing SBIR Technologies

## Success Stories

SMALL BUSINESS INNOVATION RESEARCH

## What is the SBIR Program?

The Small Business Innovation Research (SBIR) Program was created by the Small Business Innovation Development Act of 1982 to assist small businesses in transforming innovative ideas into commercial products. EPA is one of 10 federal agencies that participates in the SBIR Program. EPA's SBIR Program has two phases—Phase I is the feasibility study to determine the validity of the proposed concept and Phase II is the development of the technology or product proven feasible in Phase I. EPA also offers a Phase II Option to accelerate the commercialization of SBIR technologies. Companies that leverage third-party financial support before completing Phase II can request additional funds from EPA under the Phase II Option. This additional support is intended to encourage companies to take the steps necessary to commercialize their technologies early in the development phase. EPA issues annual solicitations for Phase I and Phase II SBIR proposals and awards approximately 40-50 Phase I and 15-20 Phase II contracts each year.

# Chapter 1: Introduction

The Small Business Innovation Research (SBIR) Program is an important part of the Environmental Protection Agency's (EPA) research and development efforts and helps the Agency in its mission to protect human health and safeguard the natural environment. Through the SBIR Program, EPA makes awards to small, high-tech firms to help develop and commercialize cutting-edge environmental technologies. The Program is intended to spawn commercial ventures that improve our environment and quality of life, create jobs, increase productivity and economic growth, and improve the international competitiveness of the U.S. technology industry.

Since initiating its SBIR Program in the early 1970s, EPA has been supporting small business innovators in the development of technologies, products, and processes that are helping the Agency to achieve its strategic, long-term goals. These goals include clean air, clean water, safe drinking water, better waste management and restoration of contaminated waste sites, preventing pollution, and reducing the health and ecological risks associated with climate change and stratospheric ozone depletion. These SBIR technologies are helping to solve many of today's complex environmental problems and to equip our Nation to address the environmental challenges of tomorrow.

It is not by coincidence that the SBIR Program has yielded so many technologies that address EPA's priority environmental problems. Each year, EPA's Office of Research and Development (ORD) issues a solicitation for SBIR proposals. The topic areas included in the solicitation are linked directly to the research priorities identified in *ORD's Strategic Plan*, which in turn are designed to help the Agency achieve its strategic, long-term goals. The SBIR Program is one of the various mechanisms used by ORD for accomplishing the research objectives described in this plan which identifies priorities to be emphasized over the next few years. These include safe drinking water, high-priority air pollutants, emerging environmental issues (with a near-term focus on endocrine disruptors), improvement of ecosystem risk assessment and health risk assessment, and pollution prevention and new technologies for environmental protection. The Strategic Plan also highlights seven areas of high importance that will continue to be a major part of ORD's research program, including: tropospheric ozone, global change, environmental monitoring, contaminated sites, exposures to pesticides and toxic substances, ecosystem water quality, and air toxics. Each SBIR solicitation topic addresses one or more of these priority research areas. These topics are derived from the specific research plans that are developed by staff from ORD and the Program Offices to address the priorities identified in the *ORD Strategic Plan*. SBIR topics range from drinking water treatment to prevention and control of toxic air emissions to hazardous waste treatment. (The topic areas in the most recent SBIR solicitation are described in the Appendix.) The SBIR topics are updated as the strategic research focus of ORD shifts to address high-priority research needs.

## ORD's Strategic Plan

In May 1996, EPA's Office of Research and Development (ORD) completed work on the *Strategic Plan for the Office of Research and Development*, which provides a blueprint for ORD's research program in the years to come. With this Strategic Plan, ORD has instituted a new system for determining research priorities based on risk assessment and risk management principles. ORD uses this plan to direct its resources toward understanding and solving priority environmental problems, while supporting EPA in fulfilling its mandates. The Strategic Plan identifies ORD's vision, mission, long-term goals, the process for identifying specific research topics and setting priorities and criteria for measuring success. The Strategic Plan was updated in 1997 to reflect ORD's continuing evolution, to elaborate on the evaluation criteria for determining research priorities, and to provide a more detailed description of ORD's high-priority research areas.

# Chapter 2: Commercialization Assistance

Over the past decade, dozens of innovative technologies and products have emerged from EPA's SBIR Program. A number of these have moved quickly from "proof of concept" to commercialization. In other cases, companies are still seeking the start-up capital or other support needed to achieve commercialization of their technologies. EPA recognizes that there are a variety of barriers to commercialization of environmental technologies, including obtaining the necessary financing. New facilities, equipment, product development, and marketing often demand more funds than are available internally to a small company.

Companies are more successful at commercializing their technologies when they begin financial planning early. One of the keys to successful commercialization is a good business plan and technology commercialization strategy. Companies that have successfully commercialized environmental technologies stress the importance of early attention to identifying the competition and the company's competitive edge, developing a marketing strategy that focuses on entering realistic markets as quickly as practicable, and assembling a strong management team to solicit partners and/or investors.

EPA has implemented several initiatives to assist small companies in overcoming the barriers to commercialization. These initiatives include: (1) requiring companies to submit commercialization plans with their SBIR proposals; (2) providing technical commercialization assistance to companies as they conduct their Phase I feasibility studies; (3) preparing and disseminating publications and resources designed to assist small businesses in commercializing their technologies; (4) organizing venture capitalist forums to help companies obtain financing; (5) sponsoring environmental forums to educate the investment and economic development communities about trends, challenges, and opportunities in the environmental industry; and (6) informing companies of the resources offered by the Small Business Administration (SBA) to small firms seeking to commercialize technologies.

## Requirements for Commercialization Plans

To encourage SBIR awardees to consider commercialization early in the develoment process, EPA now requires companies to submit an abbreviated commercialization plan as part of the Phase I technical proposal. EPA also provides commercialization technical assistance to companies during Phase I that is designed to help them prepare detailed commercialization plans, which must be submitted as part of their Phase II proposals. These detailed plans must address the following:

a. **SBIR Project:** A brief description of the company, its principal field(s) of interest, size, and current products and sales is required. A concise description of the SBIR project and its key technical objectives also must be included in the commercialization plan.

b. **Commercial Applications:** The plan should identify primary applications, markets, and uses of the technology specifying the potential customers and specific needs that will be satisfied. The contractor is not required to identify the capacity for secondary market opportunities or alternate uses associated with these markets. The contractor is expected to identify specific potential partners for the primary markets/uses identified for the technology.

c. **Competitive Advantages:** The plan should describe what is particularly innovative about the anticipated technology or product. (Innovation may be expressed in terms of applications, performance, efficiencies, or reduced cost.) It also should identify the significant advantages of the proposed product over existing technologies.

d. **Markets:** The anticipated market for the resulting technology, its estimated size, class of customers, and the company's estimated market share 5 years after the SBIR project is completed and/or first sales should be specified in the plan. It also should identify the current major competitors in the market as well as those anticipated in the future.

e. **Commercialization:** The plan should briefly describe how the company expects to produce the product (e.g., manufacture it in-house, subcontract manufacturing, enter into a joint venture or manufacturing agreement, license the product). It also should describe the approach and steps (e.g., market the product itself, market it through dealers, contract sales, marketing agreements,

sales representatives, or foreign companies; enter into joint ventures) the company plans to take to commercialize the technology or product and to achieve significant sales. In addition, the company's strategy for raising money to support commercialization activities should be delineated in the commercialization plan.

## Commercialization Technical Assistance

The Small Business Act authorizes federal agencies with SBIR programs to enter into contracts to provide technical assistance to SBIR awardees on all facets of commercialization. For each Phase I award, EPA can provide up to $4,000 of SBIR funds (above the Phase I SBIR contract award amount) for such technical assistance.

Each year, EPA engages a contractor experienced in business planning and commercialization to assist the Phase I awardees in preparing comprehensive commercialization plans. These plans typically include a description of the project, the potential commercial applications, and the competitive advantages envisioned by the company. The commercialization plans also include the results of market studies and a strategy for commercializing the technology. Over the past 2 years, this assistance has been shown to be invaluable in aiding small businesses to develop credible commercialization plans that will help them achieve their commercialization goals in a timely manner.

## Commercialization Phase II Option

EPA also offers financial assistance to accelerate commercialization of SBIR technologies through a Phase II Option. Companies that receive Phase II contracts can request additional funds from EPA if they are able to leverage third-party financial support to accelerate Phase II. This Phase II Option is not intended to extend Phase II or delay market entry, only to accelerate technology commercialization by encouraging companies to attract third-party financing before completing Phase II. EPA's Phase II Option is aimed at helping small businesses explore commercialization at the same time they are conducting the research needed to develop the technology.

## Commercialization Guides

EPA published the *Guide to Technology Commercialization Assistance for EPA SBIR Program Awardees* (EPA/600/F-97/014), which identifies federal, state, and private resources for commercialization assistance. This commercialization assistance guide presents information on various programs and organizations that offer technical and financial assistance as well as information and other resources, to small businesses and entrepreneurs. The guide also identifies resources available on the Internet that may provide useful information for companies interested in commercializing a technology. EPA also has disseminated to SBIR companies a publication entitled *Making Money With Your Technology: A Guide to Commercial Success*, which was prepared by the Research Triangle Institute under contract to the National Aeronautics and Space Administration (NASA). This guide offers insights from other companies that have successfully developed and marketed new technologies and identifies what these companies consider to be the key factors for commercialization success. EPA has plans to develop a guide that will assist small companies in obtaining financing for development and commercialization of environmental technologies and products.

## Partnering Forums

Venture capitalist forums are organized by EPA to provide SBIR companies the opportunity to meet and discuss their technologies and financing needs with large companies, venture capitalists, and other small businesses. The Agency has found that such forums are an effective means of fostering partnerships as well as investments in new technologies. These forums offer SBIR awardees the opportunity to obtain the capital and resources needed to commercialize and market their technologies. EPA also sponsors environmental forums to educate the investment and economic development communities about trends, challenges, and opportunities in the environmental industry. These environmental forums promise to be an excellent vehicle to help investors and partner companies recognize the potential of small environmental technology firms.

# Commercialization Guides For SBIR Awardees


## SBA Resources For Small Businesses

The SBA has a number of resources, many of which can be accessed on the Internet at *www.sba.gov,* to assist small businesses that are seeking commercialization assistance, including:

a. **Commercialization Matching System (CMS):** The CMS links potential sources of capital with firms that are participating in the SBIR Program.

b. **Small Business Development Centers (SBDCs):** The SBDC Program provides management and technical assistance to current and prospective small business owners.

c. **Service Corps of Retired Executives (SCORE):** Executives and business owners donate their time to counsel, educate, and advise small businesses.

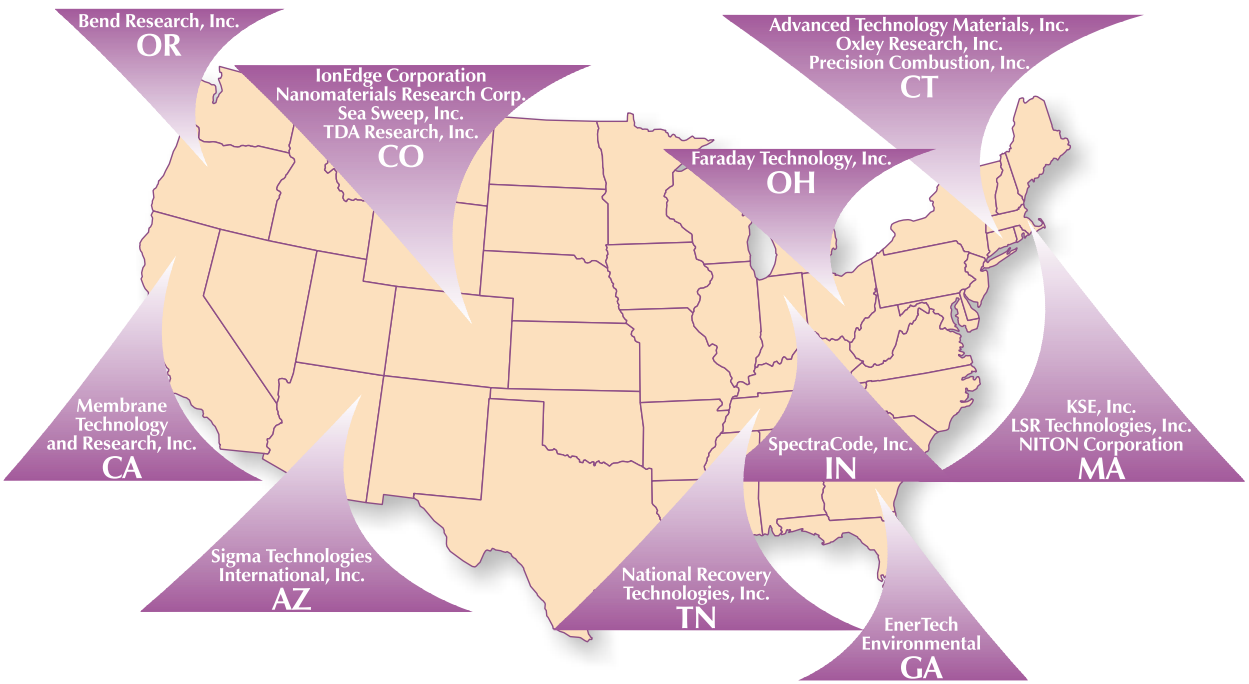
d. **Business Information Centers (BICs):** The BICs offer counseling and training services to small businesses.

e. **Small Business Investment Company (SBIC) Program**: SBICs use their own capital, plus funds borrowed at favorable rates with an SBA guarantee, to make venture capital investments in small businesses.

f. **Financial Assistance Programs**: The SBA offers low interest loans to small businesses.

g. **Angel Capital Electronic Network (ACE-*Net*)**: The ACE-*Net* is an Internet-based service that provides information to angel investors on small companies seeking equity financing.

## Where Are These 17 Successful Companies Located?




# Chapter 3: Success Stories

Dozens of small businesses have successfully commercialized technologies developed under EPA's SBIR Program. Seventeen of these companies are described in this chapter. These 17 success stories have been selected because these companies have successfully transitioned their ideas into commercially viable products which have generated revenues that exceed the funding provided by EPA's SBIR Program. Each profile includes a description of the technology, its environmental benefits, and the company's commercialization efforts.

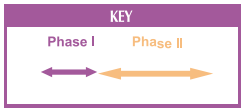
This chapter highlights just a few of the innovative technologies that have resulted from EPA's investment in research at small companies across the country. These success stories testify to the important role that EPA's SBIR Program has played in enlisting the ingenuity and creativity of America's small high-tech firms to develop innovative technologies that improve and protect our environment.






# Seventeen Companies That Successfully Commercialized Technologies Developed Under EPA's SBIR Program

| Company / Technology | Media | Page # | Year of Award |
|---|---|---|---|
| | | | 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 |
| **Advanced Technology Materials, Inc.**<br>Solid Scrubber for the Semiconductor Industry | Air | 10 | |
| **Bend Research, Inc.**<br>Membrane-Based System for the Recovery and Reuse of Solvents | Air/Hazardous Waste | 12 | |
| **EnerTech Environmental**<br>Slurry Carb™ Process for Clean Energy from Municipal Solid Waste | Pollution Prevention/ Solid Waste | 14 | |
| **Faraday Technology, Inc.**<br>E-CHANGE In-process Recycling System for Electroplating Rinsewater | Pollution Prevention/ Hazardous Waste | 16 | |
| **IonEdge Corporation**<br>Zero-Waste Dry Plating Process | Pollution Prevention/Air/ Hazardous Waste/Solid Waste | 18 | |
| **KSE, Inc.**<br>Solvent-Free Polymerization Process | Pollution Prevention/ Air/Water | 20 | |
| **LSR Technologies, Inc.**<br>Core Separator System for Controlling Particulate Emissions | Air | 22 | |
| **Membrane Technology and Research, Inc.**<br>Membrane Process to Recover Monomer in Polyolefin Plants | Air | 24 | |
| **Nanomaterials Research Corporation**<br>Hazardous Solvent-Free Manufacturing Process for Electroceramic Powders | Pollution Prevention | 26 | |
| **National Recovery Technologies, Inc.**<br>Infrared Fingerprint Sorting of Postconsumer Plastics Resins | Pollution Prevention/ Solid Waste | 28 | |
| **NITON Corporation**<br>NITON XL-309 Dual Detector Lead Paint Analyzer | Monitoring | 30 | |
| **Oxley Research, Inc.**<br>Electrolytic Regeneration Process for Restoring Acid Cupric Chloride Printed Circuit Board Etchant | Pollution Prevention/ Hazardous Waste | 32 | |
| **Precision Combustion, Inc.**<br>Microlith™ Fast Lightoff Catalytic Converters | Air | 34 | |
| **Sea Sweep, Inc.**<br>Environmentally Benign Oil Absorbent | Water | 36 | |
| **Sigma Technologies International, Inc.**<br>Surface Functionalization Process for Packaging Films to Promote Adhesion of Aqueous-Based Inks | Pollution Prevention/ Air/Hazardous Waste | 38 | |
| **SpectaCode, Inc.**<br>RP-1 Polymer Identification System for Sorting Plastics | Pollution Prevention/ Solid Waste | 40 | |
| **TDA Research, Inc.**<br>Selenium Removal Process for Petroleum Refinery Wastewaters | Water | 42 | |



# Solid Scrubber for Semiconductor Industry

### Advanced Technology Materials, Inc.
### Danbury, Connecticut

Advanced Technology Materials, Inc. (ATMI), was awarded an EPA SBIR contract to develop an innovative solid scrubbing material designed especially to reduce toxic air emissions from the semiconductor industry. With 30 times the capacity of activated carbon, the new material became the core of the Novapure dry scrubber system that was introduced into the market in 1991. The Novapure system has broad application in the electronics industry and in research and development institutions where small amounts of hazardous materials are routinely employed in chemical vapor deposition (CVD) processes.

The rapid growth of the American microelectronics industry has spawned new environmental challenges associated with the processes used to prepare semiconductor chips that are key components of sophisticated electronic devices. Silane, phosphine, and arsine are used in CVD steps in semiconductor fabrication. Although large companies have built expensive facilities for handling small amounts of these materials, small manufacturers have vented the gas to the atmosphere or used similar unacceptable techniques. As production increased, however, venting of these gases to the atmosphere was no longer an option. The Emergency Planning and Community Right-to-Know Act designates silane, phosphine, and arsine as extremely hazardous chemicals used by the semiconductor industry; these chemicals also are regulated as toxic chemicals under the Clean Air Act. ATMI's scrubber system transforms these toxic gases into nonvolatile, benign solids through chemical absorption. By neutralizing, solidifying, and concentrating hazardous effluent up to 20,000 times, this technology helps to eliminate toxic air emissions and minimize solid toxic wastes from small semiconductor manufacturers.


**ATMI's Novapure Dry Scrubber System, designed to reduce toxic air emissions from the semiconductor industry, was introduced into the market in 1991.**

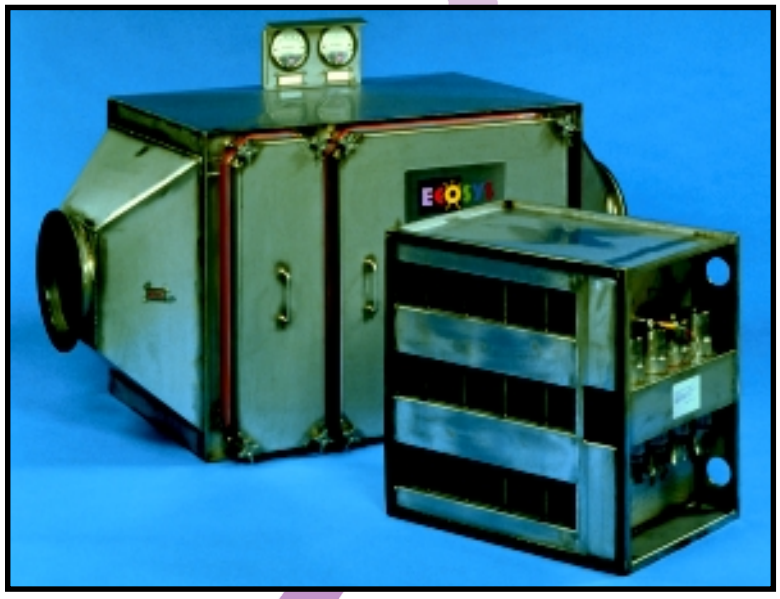
Since the award of this SBIR contract, ATMI has developed a family of novel vent gas scrubbers that are cost effective in reducing toxic air emissions from small quantity CVD processes as well as toxic air emissions released by semiconductor manufacturers. ATMI has spun off this product line into its subsidiary, EcoSys, which is now the largest supplier of point-of-use emission control equipment for the semiconductor industry in the world. EcoSys process scrubbers are smaller than traditional air pollution control equipment. Instead of a single large installation outside a fabrication plant, EcoSys products are small enough to be located at each individual pollution source.

This SBIR project also led to the development of several new safety-related products for the semiconductor industry. One product, called the Safe Delivery Source or SDS that uses absorbent materials similar to those of the dry scrubber system, eliminates the use of high pressure toxic gases in the semiconductor industry.

ATMI was granted four U.S. patents on its dry scrubber technology, and in just 3 years, the company's business grew to nearly $6 million in annual sales. To expand its environmental control equipment market, in 1994 and 1995 ATMI

acquired the rights to alternative technologies, including wet scrubbing and combustion scrubbing. These acquisitions increased ATMI's annual revenues to nearly $30 million. Since 1987, when ATMI was awarded the EPA SBIR Phase I contract, the company has grown from four employees working in a small garage in New Milford, CT, to nearly 480 employees in numerous locations around the world with revenues of more than $100 million. In recognition of its outstanding achievements in technology innovation, ATMI received the Tibbetts Award in 1996. This award is presented by the SBA to companies associated with the SBIR Program that are models of excellence in the area of high technology.

Tibbetts Award 1996



ATMI's EcoSys Emergency Release Scrubber traps unexpected releases of toxic or hazardous gases before they can escape to the atmosphere.

## SBIR Impact

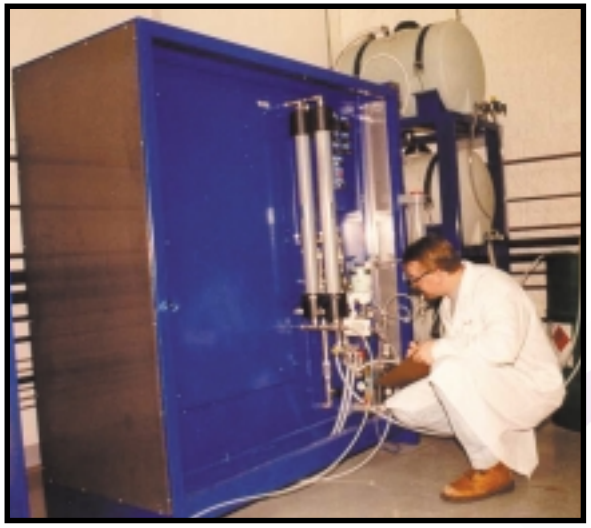
- **ATMI's dry scrubber system reduces toxic air emissions from the semiconductor industry.**
- **The innovative solid scrubbing material, the core of ATMI's Novapure dry scrubber, has 30 times the capacity of activated carbon.**
- **This SBIR contract led to the development of a family of novel vent gas scrubbers that are cost effective in reducing toxic air emissions from chemical vapor deposition processes as well as several new safety-related products that eliminate the use of toxic gases in the semiconductor industry.**
- **In 1996, ATMI received the Tibbetts Award in recognition of the company's excellence in the area of high technology.**
- **ATMI has grown from four employees in 1987 to nearly 480 employees in 1997 with annual revenue of more than $100 million.**

# Membrane-Based System for the Recovery and Reuse of Solvents

**Bend Research, Inc.**

**Bend, Oregon**

Bend Research, Inc., through funding from EPA's SBIR Program and private clients, has developed a membrane-based system for the recovery and reuse of alcohol-based solvents. More than 2.3 billion pounds of solvents are used annually in the United States in manufacturing and industrial cleaning processes. Industry is steadily increasing its efforts to eliminate chemical emissions and to reduce the costs of hazardous waste disposal that result from solvent use. In this move toward reduction of hazardous wastes, industry has focused particularly on minimizing the use of hydrocarbon and chlorinated solvents, turning toward aqueous-, alcohol-, or glycol-based solvents. Hydrocarbon and chlorinated solvents are regulated as hazardous substances and many chlorinated solvents have been identified as ozone-depleting chemicals, which are being phased out by the Clean Air Act Amendments of 1990. Replacing hydrocarbon and chlorinated solvents with alcohol-based solvents eliminates the air emissions and hazardous waste disposal costs that were associated with their use. However, the switch to these "oxygenated" solvents has made recycling even more difficult, especially when water must be removed, because many oxygenated solvents form azeotropes with water. Conventional unit operations for "breaking" azeotropes are too expensive and/or too complex to make the recycle of alcohol-based solvents practical in many applications.



**Bend Research's membrane-based solvent recovery system can dehydrate solvents, such as isopropyl alcohol, effectively to make recycling of aqueous- or alcohol-based solvents practical and cost effective.**

The membrane-based system developed by Bend Research overcomes these problems through two innovations: (1) solvent- and temperature-resistant hollow-fiber modules, and (2) a novel operating mode that maximizes system performance. In the process, the spent solvent is sent to an evaporator, and the vaporous overhead is sent to a membrane module containing permselective membranes. These highly selective "vapor-permeation" membranes allow water to pass through, while restricting the passage of the solvent. The membrane module produces a product stream of high-purity solvent that is free from contaminants and suitable for recycle. This research has resulted in patents on the membrane module and the membrane system.

Through Bend Research's spin-off company, Cascade Separations, Inc., private clients have provided funding to commercialize this technology. The initial market focus is on the recycle of isopropyl alcohol (IPA) and the production of ultrapure IPA for the electronics industry. Future market areas include the dehydration of other solvents (such as ethanol, tetrahydrofuran, and acetone) and the removal of contaminants other than water from solvents.

IPA is used as a drying agent by the electronics industry for drying parts (e.g., silicon wafers, hard disks, circuit boards). The parts are submerged into an IPA "vapor cloud," where hot IPA condenses on the cold parts and pulls off the water. The IPA/water mixture then is collected in a drip tray and removed from the dryer. The membrane-based system developed by Bend Research treats this "wet" IPA, producing dry IPA that can be reused in the dryer.

Tests have shown that the membrane-based system can take IPA contaminated with as much as 20 weight percent water and produce purified solvent containing less than 0.1 weight percent water (i.e., 99.9 weight percent IPA). This system allows reuse of the spent IPA, reducing the amount of IPA waste generated as well as the amount of new IPA that must be purchased for use in the dryer. The membrane-based system also removes particulates and metal ions from the IPA; therefore, the reprocessed IPA is often "cleaner" than newly purchased IPA.

Systems based on this technology have been in operation for more than 18 months, effectively reprocessing IPA for a hard-disk manufacturer. The systems have worked well in an industrial setting, resulting in increased yields in the disk-manufacturing process. Recently, this disk manufacturer brought another membrane-based system on line for an additional dryer.

Initial results have shown that this technology is both effective and economical. The results also have shown that improvements could be made to the hollow-fiber vapor-permeation modules to further decrease the costs of reprocessing the IPA. These improvements were the focus for the Phase II SBIR Program. The improved modules are being manufactured and will be installed soon.

By leveraging EPA funding with private-sector resources, Bend Research has successfully commercialized this membrane-based technology. The hollow-fiber vapor-permeation modules are being manufactured at Bend Research Manufacturing, a wholly owned subsidiary of Bend Research. These modules are sold to an exclusive licensee of this technology, Cascade Separations, Inc.—an engineering, systems manufacturing and marketing company that was created to provide membrane-separation systems to end users in target industries. Cascade has received funding from several private sources for commercialization of this technology. Cascade's initial market focus is providing systems for the electronics industry, with recent focus on the production of ultra-pure IPA using a modified flow scheme based on the hollow-fiber membrane technology developed by Bend Research under EPA's SBIR Program.

## SBIR Impact

- **Bend Research's membrane-based system makes the recycling of oxygenated solvents more cost effective, thus providing a desirable alternative to using hydrocarbon and chlorinated solvents that produce toxic air emissions and hazardous wastes.**
- **Bend Research has developed a membrane-based system that effectively dehydrates solvents. It can reduce the concentration of water in alcohols and other industrial solvents to as low as 10 ppm. The technology also can be used to break azeotropes.**
- **Several systems have been installed by a hard-disk manufacturer to reduce the amount of IPA required in vapor dryers used for drying parts. Results have shown that the use of this technology: decreases the amount of IPA waste generated, decreases the amount of new IPA needed, and increases manufacturing yields.**
- **The initial market focus is on IPA reprocessing and the production of ultra-pure IPA for the electronics industry. Future market areas include the dehydration of other solvents (e.g., ethanol, tetrahydrofuran, acetone) and removal of contaminants other than water from solvents.**

# Clean Energy From Municipal Solid Waste

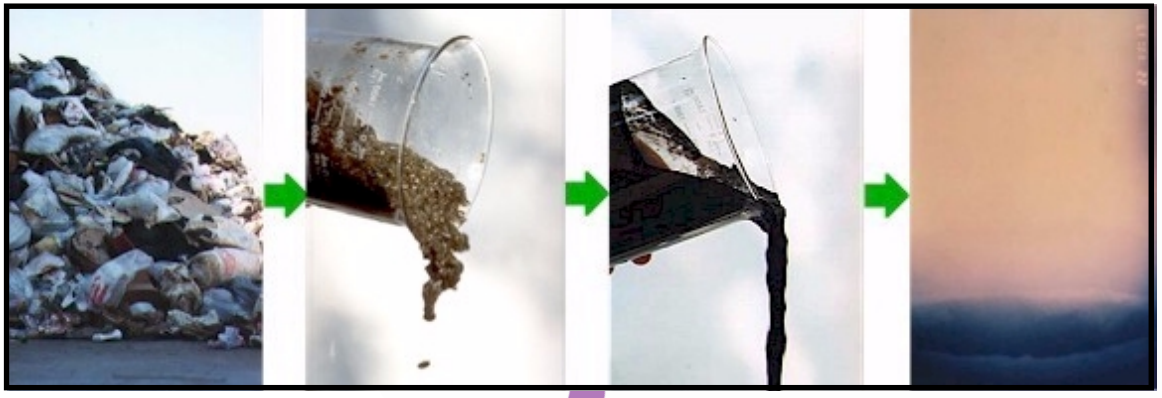
**EnerTech Environmental**
**Atlanta, Georgia**

EnerTech Environmental, with the funding provided by EPA's SBIR Program, has successfully developed the SlurryCarb™ Process, an innovative process that chemically converts municipal sewage sludge (MSS), municipal solid waste (MSW), and other organic wastes into a high-energy, liquid fuel (or slurry) that is cleaner to combust than most coals. Because the SlurryCarb™ Process eliminates the need to burn or landfill organic wastes—such as MSS and MSW—its use can help address the problem of landfill overcrowding and air emissions (e.g., VOCs, hazardous air pollutants, methane) from landfills. In addition, this technology supports EPA's strategic goal of decreasing the quantity of waste requiring disposal.

SlurryCarb™ is a highly adaptive system that can stand alone or be used in combination with existing or planned waste disposal strategies. Simplicity of operation is key to the SlurryCarb™ procedure. MSS or MSW is brought to a central manufacturing facility where it is converted into a uniform, pumpable slurry. The slurry can be created from a single waste stream such as MSS or a combination of wastes such as MSS and MSW. The product fuel, known as "E-Fuel," then can be transported through pipes or tankers to industrial and utility users where it is burned as a supplement or substitute for conventional fuels such as coal or oil.

E-Fuel™ can be produced up to 7,720 Btu/lb (wet or slurry basis) at 52.0 weight percent solids (the remainder is water) and easily fired into pulverized coal boilers via spray nozzles and combusted with less than 20 percent excess air. In addition, the SlurryCarb™ Process removes over 98 percent of the feed chlorine, greatly reducing HCl emissions and boiler corrosion from combustion of E-Fuel™. Without extensive air pollution control systems, the CO, $NO_x$, trace metal, and dioxin emissions from the combustion of E-Fuel™ are well below EPA's New Source Performance Standards (NSPS) for Municipal Waste Combustion (MWC), and the $SO_2$ emissions are comparable to the NSPS for extensive air pollution control systems.

With the SlurryCarb™ process, collected waste is processed as a fluid in continuous equipment, which provides savings in capital and operating costs. The feed waste is chemically altered so that it becomes a uniform, pumpable slurry fuel that can be used onsite or pumped, piped, or tankered to a customer. In addition, waste stream components, which typically must be cleaned from the flue gas after combustion (i.e., chlorine, ash, sulfur, etc.), instead are removed in the front-end of the process at a lower cost per ton of pollutant removed. The technical advantages of the SlurryCarb™ process all contribute to its excellent economics. A 100 ton per day sludge facility can operate profitably at a tipping fee of $40 per as received ton (assuming the sludge enters the SlurryCarb™ system at 20 percent solids). Reduced-capacity units (i.e., 25-50 tons/day) have similarly strong economics. In the United States alone, 8 million dry tons of MSS and 210 tons of MSW are produced every year. EnerTech's cost of disposal is equal to or below the average cost of conventional disposal options for these wastes. Smaller communities now have available to them



MSW | RDF Slurry | E-Fuel | Utilization of E-Fuel

**The SlurryCarb™ Process can generate a quality fuel from several low-grade fuels and wastes, including municipal solid waste and municipal sewage sludge.**

a clean and affordable method of MSS disposal that reduces landfill demands and eliminates the need for a combustion facility to burn wastes. Instead, the waste is converted to a valuable fuel and then exported to the marketplace.

Through an agreement with Mitsubishi Corporation, construction of a 20 ton/day (as received MSW) unit in Japan was completed in early 1997. EnerTech also has signed an agreement with TS Group, Ltd., to build a unit in Korea. Construction of this unit is expected to begin in 1999. Having successfully piloted this technology in the United States, EnerTech currently is working with Jacobs Engineering, the American Plastics Council, and the Westinghouse Savannah River Company to build its first commercial facility in this country by the end of 1999.

**This 20 ton/day unit, which began operating in Japan in early March 1997, was designed as a fully integrated commercial-scale system for local MSW. The product fuel from the facility is cofired in a pressurized gasifier for hydrogen production or cofired in a cement kiln for heat production.**

## SBIR Impact

- **EnerTech's SlurryCarb™ Process eliminates solid waste by converting municipal sewage sludge, municipal sold waste, and other organic wastes into a high-energy liquid fuel that burns cleaner than most coals.**
- **Because the SlurryCarb™ Process eliminates the need to burn or landfill organic wastes, its use can help address landfill overcrowding and reduce air emissions from municipal incinerators and landfills.**
- **The economic and operational viability of the SlurryCarb™ Process has been successfully demonstrated at the 20 ton/day level using municipal solid waste as a feedstock.**
- **EnerTech is negotiating with a consortium of companies to construct a 100 ton/day facility in the United States, which will springboard this technology into the U.S. commercial market.**

# In-Process Recycling of Contaminated Electroplating Rinse Water Utilizing a Modulated Electric Field and In-Situ Regeneration

**Faraday Technology, Inc.**
**Dayton, OH**

Faraday Technology, Inc. (FaraTech) has developed the patented E-CHANGE™ In-Process Recycling System with funding from EPA's SBIR Program. The E-CHANGE™ System can recycle approximately 90 percent of contaminated electroplating rinse water back into the plating process.

Contaminated rinsewaters from electroplating have been traditionally treated onsite by conventional hydroxide precipitation, resulting in solid-phase wastewater treatment sludges. In 1992, there were releases of 73,000 metric tons of copper/lead compounds and 227,000 metric tons of metals to the environment. Costs associated with the transport and disposal of copper/lead sludges and metal sludges were in excess of $25 million and $62 million, respectively, with additional costs associated with the liability of future landfill cleanup.

E-CHANGE™ offers the environmental benefit of nearly eliminating the generation of copper/lead sludges, which are regulated by EPA as hazardous substances. This system can save the average electroplater thousands of dollars by eliminating hazardous waste transport and disposal costs and reducing annual water and sewer expenses. It also saves electroplaters money by recovering the metal content of the rinse water.

The E-CHANGE™ system is a unique, hybrid technology utilizing the benefits found in conventional ion-exchange and electrowinning. The system utilizes a Modulated Electric Field (MEF) to enhance mass transport and to enable electric regeneration to occur *in situ*. Fara-Tech's objective in developing this technology was to provide the "average" job shop plater with "point-source" pollution prevention capabilities at a cost-effective price with a return on investment (ROI) of less than 12 months. Testing indicates that the E-CHANGE™ system can recycle approximately 90 percent of the contaminated rinse water (10 percent of the rinse water is lost due to evaporation). The dilute stream is adjusted for pH and used for rinsing plated parts. The concentrate is used to make up the plating solution, automatically readjusted for plating *in situ* without creating a secondary waste stream.

**Faraday's E-Change™ In-Process Recycling System is capable of recycling approximately 90 percent of the contaminated electroplating rinse water back into the plating process, nearly eliminating metal sludges and significantly reducing water use.**

FaraTech has validated this technology using two limited Beta tests for acid copper rinse water. FaraTech has delivered two systems, one for a limited production printed wiring board (PWB) manufacturing facility and another for a government research facility. Additional laboratory data have been compiled for lead-tin rinse water with a Beta test scheduled for late 1999.

FaraTech also has completed feasibility studies for the decontamination of hexavalent chromium and electroless nickel plating baths, and FaraTech plans to exploit this innovative technology for other rinse water constituents such as nickel and zinc.

FaraTech's commercialization efforts have included: (1) product promotion at professional society/industry conferences; (2) substantial corporate investment in both manufacturing issues and intellectual property; (3) a detailed economic analysis, including complete system cost and estimated system pricing scenarios; and (4) detailed discussions with several potential vendors for market distribution of the technology.

By implementing a unique business strategy that utilizes a "Technology Rich Platform" based on the scientific ways in which asymmetrical electric fields influence electrochemical processes, FaraTech is developing multiple products and processes for various markets. The platform represents a new way of applying electrochemical principles to the electroplating/metallization, fuel cell/power supply, machining, environmental, and corrosion market segments. FaraTech has three U.S. patents issued, seven U.S. patents pending, one foreign patent pending, and five additional U.S. patent applications to be filed in 1999.

## SBIR Impact

- **FaraTech's E-CHANGE™ can recycle approximately 90 percent of the contaminated electroplating rinse water back into the plating process. The system nearly eliminates the generation of metal sludges, and the liability associated with their transportation and disposal.**
- **FaraTech's innovative in-process recycling system is designed to provide the "average" job shop plater with a "point-source" pollution prevention capability at a cost-effective price with a return on investment of less than 12 months.**
- **FaraTech's system also saves the average electroplater thousands of dollars in sludge disposal costs and water and sewer expenses.**
- **Two E-CHANGE™ Systems for acid copper applications are being built—one for a limited production printed wiring board manufacturing facility and the other for a government research facility. An additional E-CHANGE™ System is undergoing a Beta test at a specialty wire manufacturing facility for a lead-tin solder process.**

# Zero-Waste Dry Plating

**IonEdge Corporation**
**Fort Collins, Colorado**

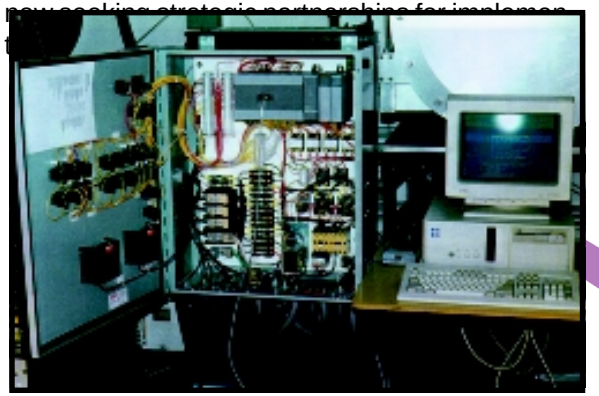
IonEdge Corporation, with the funding provided by EPA's SBIR Program, has developed and commercialized an innovative metal plating technology that results in "zero-waste." It eliminates most of the air emissions, wastewater, and solid and hazardous wastes associated with zinc and cadmium plating. One EPA study noted that electroplating effluents are the single largest source of natural water contamination in the United States (Electroplating Wastewater Sludge Characterization, EPA-600/52-81-064). Much of the waste from conventional electroplating operations is associated with contaminated rinse waters, which require treatment and subsequent disposal of a hazardous sludge in an approved landfill. IonEdge's process eliminates the costs and liabilities related to the transport and disposal of hazardous sludges; waste treatment savings are estimated to exceed $1,000 per day for the average electroplater. Because IonEdge's plating process takes place in a sealed chamber, it also minimizes operator exposure to hazardous particle emissions and eliminates solid waste by facilitating *in situ* recycling of the metals used in the plating process. In addition, this dry plating process uses less chemicals, requires 75 percent less energy, and reduces water consumption by an order of magnitude in comparison to conventional electroplating processes.

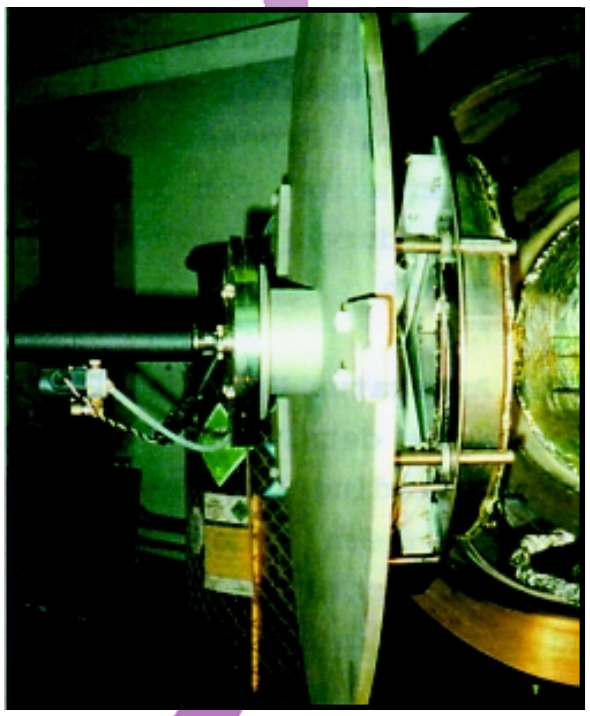
Zinc and cadmium coatings are electroplated on steel hardware components used in the defense, aerospace, automotive, and construction industries to protect them from corrosion in natural environments. The electroplating process is occupationally and environmentally hazardous because it requires the use of toxic liquids and generates large quantities of contaminated wastewater and solid and hazardous wastes.

To address environmental and occupational issues related to electroplating, IonEdge achieved zero-waste plating by using the novel concept of a vapor bath inside a vacuum in lieu of the conventional liquid bath in air. Furthermore, special technological features of the IonEdge process allow for material recycling. Only the parts exiting the chamber are plated, leaving the chamber and racks free of deposits. The sealed chamber operation also minimizes operator exposure to hazardous particle emissions. The dry-plating line consists of only four process steps as opposed to a dozen bath operations in conventional electroplating, and a waste treatment facility is unnecessary.

A rack plating apparatus using IonEdge's process has been in production for more than 2 years. For a batch of parts, the start-to-finish process time for the degrease-to-chromate operation is about 30 minutes. The quality of IonEdge's cadmium coatings has been acceptable according to standard federal and U.S. military specifications, and the coatings have performed well in more than 7,000 hours in salt-fog tests. The apparatus and process developed during the EPA SBIR project were upgraded and improved to meet customers' requirements in pilot production. In-process improvements and adjustments were made to maintain product quality and to achieve process repeatability. Test samples from three prospective customers were coated on the pilot line. The quality of these coatings was evaluated and approved by all three customers.

This success led to the first commercial sale of the dry-plating process to an aerospace customer who requested IonEdge to set up three additional processes to complete the customer's plating line. The expanded plating line and processes have been certified for coating aerospace parts, and IonEdge continues to provide coating services to the aerospace industry. During 1998 alone, more than 50,000 steel components were cadmium dry plated on this plating line. These components are now in service in commercial airplanes, jet fighters, helicopters, and missiles. IonEdge is preparing a business plan for expanding the dry-plating line to increase the throughput by an order of magnitude (in the range of 2,000 parts of 1-inch size/hour). Simultaneously, a full commercial production plating line will be installed for high-volume parts processing (10,000 parts/hour), which will allow customers to evaluate the full economic benefits of the dry-plating process. IonEdge is now seeking strategic partnerships for implemen-





IonEdge achieved zero-waste plating by using the novel concept of a vapor bath inside a vacuum in lieu of the conventional liquid bath in air. This technology eliminates most waste associated with plating; reduces chemical, water, and energy consumption; and significantly reduces waste treatment costs.

## SBIR Impact

- **IonEdge has developed a zero-waste dry plating process that eliminates most of the air emissions, wastewater, and solid and hazardous wastes associated with zinc and cadmium plating.**
- **IonEdge's dry plating process eliminates the need for conventional toxic plating bath liquid chemicals and minimizes the liabilities related to the transport and disposal of hazardous sludges.**
- **The zero-waste dry plating process is economical—it requires 75 percent less energy, reduces water usage by an order of magnitude, and results in waste treatment cost savings of approximately $1,000 per day, for an average electroplater.**
- **IonEdge's in-house dry plating line has been certified for use by an aerospace company. IonEdge is seeking strategic partnerships for implementation of a plan to expand the dry plating line to increase throughput by an order of magnitude, along with installation of a full commercial production line for high-volume processing (10,000 parts/hour).**

# Solvent-Free Polymerization Process

**KSE, Inc.**
**Amherst, Massachusetts**

KSE, Inc., through funding provided by EPA's SBIR Program, has developed a polymerization process that produces methyl vinyl ether and maleic anhydride (MVE/MAN) copolymers without the use of benzene. Benzene is regulated as hazardous under the Clean Air Act, the Safe Drinking Water Act, the Resource Conservation and Recovery Act, and the Clean Water Act. EPA has classified benzene as a known human carcinogen of medium carcinogenic hazard. Long-term exposure to benzene at various levels has been determined to be carcinogenic by the U.S. Department of Health and Human Services, and it also may be harmful to the immune system.

Benzene and other toxic chemicals have been used as solvents for decades. A particularly important example is the use of benzene as the polymerization solvent in the synthesis of copolymers of MVE/MAN. Approximately 150 million pounds of benzene are consumed annually in the manufacture of the 25 million pounds of MVE/MAN copolymer that are produced in the United States each year. The copolymer product from this process is centrifuged and then dried—both steps resulting in benzene emissions. MVE/MAN copolymer product has been sold containing up to 2 percent benzene by weight. KSE's solvent-free polymerization process could eliminate the use of this 150 million pounds of benzene, the health risks associated with benzene emissions during the polymerization process, and the health risks associated with residual benzene in consumer products that are manufactured with MVE/MAN copolymer. It is used, for example, in the manufacture of the most widely used denture adhesive in the United States. The copolymer reacts with saliva to produce a strong adhesive between false teeth and gums.

The copolymer from KSE's innovative process has been subjected to extensive polymer property tests to demonstrate that it is functionally identical to the copolymer produced from the classical benzene technology. Laboratory tests, using methods certified by the Food and Drug Administration, have shown the copolymer to be of ultra-high purity, containing nondetectable benzene at a quantitative limit of 10 ppb. In addition to eliminating benzene from the MVE/MAN copolymer, KSE's process has been demonstrated to be more efficient and cost-effective than classical benzene technology. The reaction rate of the KSE process is much faster, leading to more than a 10-fold improvement in reactor cycle time. Fewer solvent separation steps are required in the KSE technology, and the copolymer drying step is faster and more energy efficient than that of the classical benzene technology.

Before committing to purchase copolymer produced using KSE's process, customers have required that long-term product qualification tests be performed on replicate batches of commercial production of the copolymer to confirm that the co-

**KSE, Inc.'s solvent-free polymerization process produces MVE/MAN copolymers without the use of benzene. This innovative process reduces the environmental and health risks associated with MVE/MAN copolymers, and it is more efficient and less costly than classical benzene technology.**

polymer can successfully be converted into the desired product (e.g., denture adhesive). The EPA SBIR funding provided KSE the critical resources needed to initiate a large-scale manufacturing optimization and test program to prove the copolymer product efficacy through customer qualification testing—a step that would not have been possible without this funding.

Product qualification tests, conducted by major consumer products companies, concluded that the performance of KSE's copolymer is excellent. ChemDesign Corporation, a subsidiary of the Bayer Corporation, has signed a letter of intent to manufacture the copolymer. Plant production of the copolymer is expected to begin in 1999.

By combining EPA funding with private-sector resources, KSE has successfully commercialized its solvent-free polymerization process, which will reduce the health and environmental risks associated with the production and use of MVE/MAN copolymers and provide a more efficient and cost-effective method of production the copolymer. The production cost of the KSE benzene-free copolymer is substantially less than the current selling prices of $4 to $6 per pound for existing commercial MVE/MAN copolymers produced using the classical benzene technology.

## SBIR Impact

- **KSE, Inc., has developed a polymerization process that produces methyl vinyl ether and maleic anhydride (MVE/MAN) copolymers without the use of benzene.**
- **Health and environmental risks associated with the use of benzene in the production of MVE/MAN copolymer are eliminated.**
- **Health risks associated with residual benzene in consumer products manufactured with MVE/MAN copolymer are eliminated.**
- **KSE's process is more efficient and less expensive than the classical benzene technology.**
- **ChemDesign Corporation, a subsidiary of Bayer Corporation, has signed a letter of intent to manufacture MVE/MAN copolymer using KSE's process. Production is expected to begin in 1999.**

# Control Device for Particulate Emissions

**LSR Technologies, Inc.**
**Acton, Massachusetts**

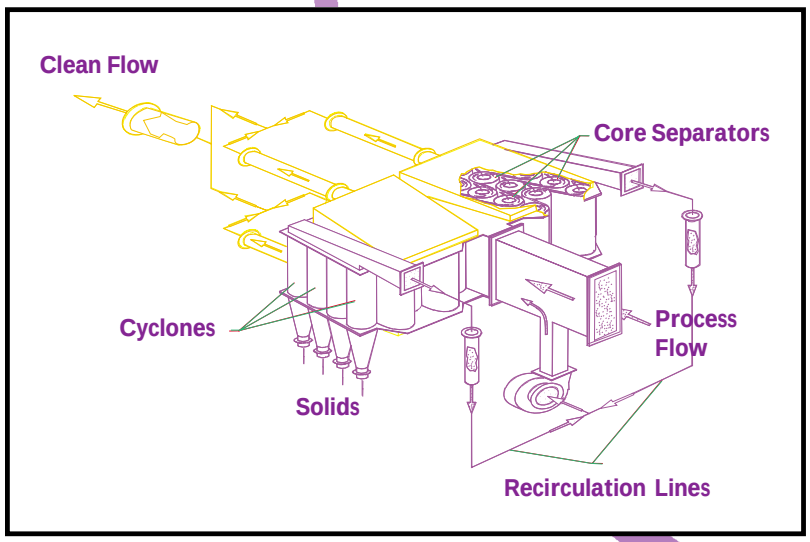
With funding from EPA's SBIR Program, LSR Technologies, Inc., has developed the Core Separator, a mechanical dust collecting device that removes micron- and submicron-sized particles from gas streams. Historically, mechanical collectors have been ineffective in removing particles with diameters of less than 10 microns.

It is likely that particulate matter will be regulated as a criteria air pollutant (i.e., pollutants causing human health impacts due to their release from numerous sources) under the Clean Air Act. EPA has proposed tightening the National Ambient Air Quality Standards for the allowable levels of particulate matter, decreasing the size of the particles that must be removed from gas streams from 10 microns to 2.5 microns. Unlike other mechanical collectors, the Core Separator is capable of removing dust particles with diameters of less than 10 microns; it even can remove a high percentage of particles in the micron range. This is equivalent to the performance of a medium-efficiency electrostatic precipitator (ESP) and better than the performance of a high-energy Venturi scrubber. Yet, the Core Separator still has the traditional advantages of mechanical collectors such as simplicity, reliability, compactness, and low maintenance.

The Core Separator system includes two conventional components, a cyclone collector for extracting solids and a fan for flow recirculation. A complete system is actually a multitude of cylindrical units, each with a single inlet for the stream to be treated and two outlets. One outlet is for the clean gas stream and the other contains a highly concentrated recirculation stream. The dust-laden recirculation stream is fed to a cyclone and returned again by means of the fan. The Core Separator component cleans the inlet stream and detains dust particles in the system. Because its efficiency is very high, most particles do not leave the system. They recirculate until collected by the cyclone. Two factors govern the performance of Core Separators: (1) high separation efficiency of the separator component, and (2) the interaction between individual components. To achieve high separation efficiency, a proper bleed-flow ratio (i.e., ratio of the recirculation flow to the total flow) is required. By controlling bleed flow, the tangential and radial velocities are controlled independently to maintain them in the desirable range.

High efficiency in the Core Separator results from low particle reentrainment. The system is designed to avoid formation of toroidal vortices. Because the Core Separator component functions as a separator and not a collector, a flow U-turn within the device can be avoided. It is entirely cylindrical, and surfaces promoting formation of vortices are moved away from the clean outlet. This theory has been verified by actual testing and through computer modeling using computational fluid dynamics (CFD) to study flow fields. It should be noted that each of these factors individually cannot prevent vorticity; however, working together they achieve what each cannot do independently. The conflicting processes of separation and solids collection are accomplished separately and in different components. The interaction between components is the principal means of attaining high system efficiency.

There is strong demand for the Core Separator both as an air pollution control device and as a means to recover valuable product material. More than 50 Core Separators have been sold in the United States and abroad, and at least one com-




**LSR Technologies' Core Separator System consists of a series of cylindrical units, each with a single inlet for the stream to be treated and two outlets. One outlet is for the clean gas stream and the other is for the highly concentrated recirculation stream. The dust-laden recirculation stream is fed to a cyclone where solids are extracted and returned again by means of the fan, which facilitates flow recirculation.**

pany using the technology for recovery of chemical catalysts has experienced a payback period of less than 6 months. In 1996, the Core Separator was selected for the prestigious R&D 100 Award, signifying it as one of the world's best new technology-based products of the year. This product is quite significant in light of the fact that very few advances have occurred in particulate control technology in recent years.

Another emerging industrial application for the Core Separator is as a control device for collecting particulate matter upstream of regenerative thermal oxidizers (RTOs), which are used in the production of wood products for the building industry (e.g., medium density fiberboard, particleboard, and oriented strandboard). The Core Separator currently is being demonstrated for wood dryer applications and could emerge as the "Best Available Control Technology" (BACT) for these processes.

More than 50 Core Separators, such as the one at the asphalt plant above, have been installed in the United States and other countries to remove dust particles from gas streams.


## SBIR Impact

- **LSR Technologies' Core Separator can remove micron- and submicron-sized particles from gas streams.**
- **By removing micron-sized particles from gas streams, the Core Separator reduces particulate matter emissions and the human health and environmental effects associated with this criteria air pollutant.**
- **More than 50 Core Separators have been sold in the United States and abroad. These units are attributed with a major reduction of particulate air emissions. For example, stack compliance testing has shown particulate emissions to be below 100 mg/nm$^3$ when used on coal-fueled boilers.**
- **A Core Separator installation used for recovery of chemical catalysts by a Fortune 500 company has produced a payback in less than 6 months.**

# Monomer Recovery in Polyolefin Plants

### Membrane Technology and Research, Inc.
### Menlo Park, California

Membrane Technology and Research, Inc. (MTR), with support from EPA's SBIR Program, has developed and commercialized a membrane process to recover valuable monomer feedstocks in polyolefin plants.

Polyethylene and polypropylene manufacture are the largest production processes in the United States, generating raw materials that are the basis of many plastic products. More than 100 polyolefin manufacturing plants are operating in this country, producing 30 billion pounds of polymer each year with an additional 200 plants worldwide. Most of these plants produce gas streams that are flared, wasting valuable feedstocks and contributing to emissions of VOCs. An estimated 100,000-200,000 tons of recoverable monomer are flared at U.S. polyolefin plants each year, which accounts for most of the VOCs emissions from these plants. VOCs are regulated as a criteria air pollutant under the Clean Air Act.

MTR's membrane process recovers essentially all of the monomer feedstock, solvent, and nitrogen from the vent gas resulting from resin purge operations for reuse in the polyolefin plant. Use of MTR's innovative process will eliminate the release of the VOCs and will provide the average polyolefin plant an annual recovery value of about $1 million.

In a typical olefin polymerization process, monomer plus catalyst, various comonomers, solvents, and stabilizers are contacted at high pressure in a reactor. The polymer product of the olefin reaction contains significant amounts of monomer and other organics, which must be removed before the polymer can be used. In most plants, the raw polymer is passed to large resin purge bins where nitrogen removes the absorbed monomer and processing solvents. The waste gas from these resin purge operations represents an important recycling and recovery opportunity. The vent gas from a typical resin purge bin contains 500-1,000 pounds per hour of recoverable nitrogen.

Before the development of the monomer/nitrogen separating membranes by MTR, no acceptable method of treating the vent gas was available. Condensation under pressure is costly and not effective; lean oil absorption technology has been tried, but it is not commercially accepted. MTR's membrane process recovers essentially all of the valuable monomer feedstock, solvent, and nitrogen from the vent gas for reuse in the plant. The membrane unit fractionates the vent gas into two streams—a monomer/solvent-rich stream and a nitrogen stream. The organic components are recycled as a concentrated gas or a condensed liquid to the polymerization reactor. The 97-99+ percent nitrogen stream is reusable in the degassing step, thereby reducing nitrogen consumption. MTR's process is closed loop; therefore, no secondary waste streams are produced.

**This MTR system was installed at a Huntsman Corporation Polypropylene Plant for recovery and direct recycle of propylene monomer.**

Membrane separation systems to treat the large vent gas streams generated in polyolefin plants require several hundred square meters of membrane. Development of the capability to produce large membrane modules was the breakthrough that allowed MTR to build systems large enough to treat polyolefin plant vent streams.

The first monomer recovery system, incorporating 50 modules and about 280 square meters of membrane, was installed in 1996, at a new polypropylene plant for Dutch State Mines (DSM), The Netherlands. By recovering monomer and minimizing nitrogen consumption, DSM expects to save about $1 million annually, yielding a system payback period of 1 to 2 years. Since then, several systems have been installed as retrofits in existing plants or in new plants in the United States and overseas. MTR has opened an office in Houston to market its technology to American polyolefin plants and to service those systems already installed. MTR's systems are sold under the company's VaporSep product line that is broadly applicable to recovery of VOCs from gas streams.

In recognition of the significance of this olefin recovery technology, MTR was awarded the 1997 Kirkpatrick Chemical Engineering Achievement Award. This biennial award, presented by the Chemical Engineering journal since 1933, recognizes the most noteworthy chemical engineering technology commercialized throughout the world during the preceding 2 years.


## SBIR Impact

- **MTR has developed a membrane process that recovers valuable monomer feedstock, solvent, and nitrogen from waste gas streams of polyolefin manufacturing plants.**
- **MTR's technology eliminates most of the VOCs emissions from polyolefin plants by eliminating the flaring of waste streams containing recoverable monomer.**
- **The first monomer recovery system was installed at a new polypropylene plant in The Netherlands in 1996. By recovering monomer and minimizing nitrogen consumption, the plant should save about $1 million annually, yielding a system payback period of 1 to 2 years.**
- **Since 1996, several systems have been installed as retrofits in existing plants or in new plants in the United States and other countries. This success has allowed MTR to transition to a manufacturing company in addition to retaining its commitment to developing new technologies. More employees have been added as a result.**